Diffractive and exclusive dijets at CDF

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Hadronic Interactions

**Non-diffractive:**
- Color-exchange

**Diffractive:**
- Colorless exchange with vacuum quantum numbers

**Goal:** understand the QCD nature of the diffractive exchange
Definitions

\( pp \rightarrow p + X \)

\( \xi, t \)

\( \Delta \eta = -\ln \xi \)

\( \beta = x / \xi \)

\( dN/d\eta \)

\( m_x \)
Diffraction at CDF

Elastic scattering

$\sigma_T = \text{Im } f_{el} (t=0)$

Total cross section

$\phi$

$\eta$

GAP

OPTICAL THEOREM

SD

DD

DPE

SDD = SD + DD
Regge theory
$\sigma_{SD}$ exceeds $\sigma_T$ at $\sqrt{s} \approx 2$ TeV.

Renormalization
Pomeron flux integral (re)normalized to unity

$\int_{\xi_{\text{min}}}^{0} \int \sigma_{\text{IM}}(t, \xi) \, d\xi \, dt = 1$

$\sigma_{SD} \sim s^{2\varepsilon}$
$M^2$-scaling

\[ \frac{d\sigma}{dM^2} \propto \frac{S^{2\varepsilon}}{(M^2)^{1+\varepsilon}} \rightarrow 1 \]

\[ \varepsilon \equiv \frac{\Delta}{M^2} \]

\[ \sigma \propto (\frac{S}{M^2})^2 \]

\[ \text{Factorization breaks down so as to ensure } M^2\text{-scaling!} \]
DIFRACTIVE STRUCTURE FUNCTION

$$R(x_{Bj}) \equiv \frac{\text{Rate}_{jj}^{SD}(x_{Bj})}{\text{Rate}_{jj}^{ND}(x_{Bj})}$$

$$\Rightarrow \frac{F_{jj}^{SD}(x_{Bj})}{F_{jj}^{ND}(x_{Bj})}$$

Systematic uncertainties due to energy scale and resolution cancel out in the ratio
Diffractive Structure Function
Breakdown of QCD Factorization

$p\bar{p} \rightarrow p + \text{dijet} + X$

Reggeon
\(\sim 10-20\%\)

\(\beta = \frac{x}{\xi}\)
\[ \frac{d\sigma_{\text{incl}}}{d\xi} \propto \text{constant} \]

\[ F_{jj}^D(\beta, \xi) \propto \frac{1}{\beta^n} \cdot \frac{1}{\xi^m} \quad (n = 1.0 \pm 0.1, \quad m = 0.9 \pm 0.1) \]
The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS.
$E_T$ distributions

CDF Run II Preliminary

- SD
- ND

ND norm. to SD
Jet $E_T > 5$ GeV

$E_T^* = (E_{T1}^{jet} + E_{T2}^{jet})/2$ (GeV)

ND norm. to SD
Jet $E_T > 7$ GeV

CDF Run II Preliminary

120 GeV
Diffractive Structure Function: $Q^2$ dependence

$E_T^{jet} \sim 100$ GeV!

Small $Q^2$ dependence in region $100 < Q^2 < 10,000$ GeV$^2$

$\Rightarrow$ Pomeron evolves as the proton!
Diffractive Structure Function: $t$- dependence

Fit $d\sigma/dt$ to a double exponential:

$$ F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t} $$

- No diffraction dips
- No $Q^2$ dependence in slope from inclusive to $Q^2 \sim 10^4 \text{ GeV}^2$
- Same slope over entire region of $0 < Q^2 < 4,500 \text{ GeV}^2$ across soft and hard diffraction!
Luminosity Run – Jan 2006

Physics goals:

- t-distributions up to $t \sim 4 \text{ GeV}^2$
- Jet-Gap-Jet fraction vs. $\Delta y_{\text{gap}}$

Low Lum $\sim 0.5 \text{E}^{30}$

$\Delta y_{\text{gap}} = \Delta y_{\text{jet}} \Rightarrow \text{BFKL}$

$\Delta y_{\text{gap}} \neq \Delta y_{\text{jet}} \Rightarrow \text{composite}$
Diffraction for All

Run I
- Suppression of single gap diffraction
- $M^2$ - scaling: $d\sigma/dM^2$ independent of $s$
- Non-suppressed double-gap to single-gap ratios

Run II
- Diffractive structure function vs $x_{Bj}$, $Q^2$, and $t$: similar to proton structure function
- Diffractive $t$ distributions: slope independent of $Q^2$

Composite Pomeron made up from proton pdf’s
http://physics.rockefeller.edu/dino/myhtml/talks/lathuile07.pdf
EXCLUSIVE DIJET PRODUCTION

Look for signal as $R_{jj} \rightarrow 1$

Use it to kill overlaps

$R_{jj} = \frac{M_{jj}}{M_X \text{(all calorimeters)}}$
DATA SAMPLES

DPE sample:

\[ J5 \cdot RPS \cdot BSC^{1}_{p} \cdot VTX \cdot RPST \cdot JET. \]

IDPE sample:

\[ DPE \cdot LRG_{p} \cdot \xi^{X}_{p}. \]

Jet η-correlations ➔ enhance signal

Examine two regions

A - signal enhanced
B - bgd dominated
SEARCH FOR THE SIGNAL

Excess over inclusive DPE dijet MCs observed at high $R_{jj}$

→ Examined for consistency with exclusive dijet signal
Data vs MC in bgd Region B

(a) $E_T = (E_{T1}^{jet1} + E_{T2}^{jet2}) / 2$

(b) $M_{jj}$ (GeV)

(c) $\eta^* = (\eta_{tot1}^{jet1} + \eta_{tot2}^{jet2}) / 2$

(d) $M_x$ (GeV)
$R_{jj}$ and $\eta^*$ in Signal Region A

![Graphs showing $R_{jj}$ and $\eta^*$ distributions for different jet conditions.](image)
Underlying Event: Data vs MC

MC vs data UE distributions

central
detector
tower
thresholds

region
transverse
to dijet $\phi$

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Data Compared to MC Predictions

- DPEMC
  - normalization high
  - slope low

- ExHuME

- KMR $\times \frac{1}{3}$

- Sudakov suppression?

- $\text{Jet}_{\text{ET}}^\text{min}(\text{GeV})$
Heavy Flavor Dijets

HF suppressed at high $R_{jj}$

Incl/MC & Incl/HF agree

HF and inclusive data normalized at $R_{jj} < 0.4$
Extracted $M_{jj}$ Distribution

Extract $M_{jj}$ distribution using ExHuME normalized to data $\sigma_{jj}^{excl}(E_T)$

- $|\eta^{jet1,2}| < 2.5$
- $3.6 < \eta_{gap} < 5.9$
- $0.03 < \xi_p < 0.08$

Higgs mass region
The Roman-Pot Detectors at CDF

In the Tevatron Tunnel

CDF had three Roman pots (RP1, RP2, RP3) located 57m downstream of the interaction point along the antiproton beam direction. They were used to detect antiprotons which underwent a “diffractive” interaction and were scattered in a direction very close to that of the original beam.

Path of the Antiproton through the Tevatron Magnets

- Dipole magnets bend recoil antiprotons which have lost momentum towards the inside of the Tevatron ring, into the Roman pots.
- Knowledge of the beam optics, the collision vertex position, and the antiproton track position and angle in the Roman-pot detectors are used to reconstruct the kinematics of the diffractive antiproton.

Physics Using the Roman-Pot Detectors

- The Roman-pot detectors are used to study diffractive interactions.
- Elastic scattering was measured by CDF in 1986-1989 using Roman pots (not those described here) in both the proton and antiproton direction.

Roman-Pot Detector Design – by The Rockefeller University

The three Roman pots each contain detectors consisting of:

- Trigger scintillation counter 2.1x2.1x0.8 cm³
- 40 X + 40 Y fiber readout channels
  - Each consists of 4 (→ bigger signal) clad scintillating fibers 0.8x0.8 mm²
    (new technology at the time)
  - X, Y each have 2 rows of 20 fibers spaced 1/3 fiber width apart for improved position resolution (three times better than with a single row)

Concept of a Roman Pot

Bellows allow detectors to move close to the beam while maintaining vacuum.

Bellows: expanded → pot out
Bellows: contracted → pot in

Reconstructed track:
- A bunch of fibers

Elastic Scattering:
- The proton and antiproton escape in the forward direction very close to the beam direction.

Non-Diffractive:
- Elastic scattering, nothing in the central detector.

Dipolar interaction, the proton escapes in the forward direction where it can be detected in the Roman pots.

Single Diffractive:
- Dipole magnets bend the beam around the ring and the diffractive antiprotons into the Roman pots.

Double Pomeron Exchange:
- Dipole magnets bend the beam around the ring and the diffractive antiprotons into the Roman pots.
- Electrostatic separators separate the proton and antiproton beams.
- Low-beta quadrupoles focus the beams at the CDF interaction point.

Top View:
- A bunch of fibers
- Roman pot
- Detector
- Bellows
- Motor to drive bellows

Side View:
- X fibers
- Y fibers
- Bellows
- Detector

The Roman-Pot Detectors at CDF

CDF “Tokyo”-Pot Detectors – Built by the University of Tsukuba, Japan

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